Electronic Version

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Claims

[c1] A method for determining a property of a flowing fluid by nuclear magnetic resonance, comprising:
applying a static magnetic field to the flowing fluid;
acquiring a suite of nuclear magnetic resonance measurements on the flowing fluid using a pulse sequence comprising a spoiling pulse, a wait time, and an acquisition pulse sequence, wherein the suite of nuclear magnetic measurements have different values for the wait time; and
fitting the suite of nuclear magnetic resonance measurements to a forward model for responses of the flowing fluid to derive a parameter selected from a flow speed, longitudinal relaxation times of the flowing fluid, and a combination thereof.

[c2] The method of claim 1, wherein the acquisition pulse sequence comprises one selected from a spin-echo pulse sequence and a single pulse.

[c3] The method of claim 1, wherein the fitting is performed by inversion of the forward model.

[c4] The method of claim 1, further comprising estimating a

viscosity of the flowing fluid based on the derived flow speed and a pressure drop across a selected length of a pipe in which the flowing fluid travels.

[c5] The method of claim 4, wherein the estimating is according to one selected from

$$\eta = \frac{\Delta P \cdot r_o^2}{8 \cdot v \cdot L} \quad \text{and} \quad \eta = K \frac{\Delta P}{v},$$

where □ is the viscosity, v is an average speed of the flowing fluid, L is the selected length of the pipe, ΔP is the pressure drop over the selected length of the pipe, and r_o is a radius of the pipe, and K is an experimentally determined constant.

[c6] The method of claim 1, further comprising estimating a viscosity of the flowing fluid based on the derived longitudinal relaxation times and a gas-oil ratio of the flowing fluid.

[c7] The method of claim 6, wherein the estimating is according to:

$$\eta_o = \frac{k\,T}{T_{1,LM} \cdot f(GOR)}$$

where □$_o$ is the viscosity, k is an empirically determined constant for the flowing fluid, T is a temperature in Kelvin, $T_{1,\,LM}$ is a logarithmic mean of the longitudinal relaxation times of the flowing fluid, and f(GOR) is an empirically determined function of the gas-oil ratio.

[c8] A method for determining a property of a flowing fluid by nuclear magnetic resonance, comprising:
applying a static magnetic field to the flowing fluid;
acquiring a suite of nuclear magnetic resonance measurements on the flowing fluid using a pulse sequence comprising a longitudinal relaxation investigation pulse sequence and an acquisition pulse sequence, wherein the suite of nuclear magnetic measurements have different values for a delay time within the longitudinal relaxation investigation pulse; and
fitting the suite of nuclear magnetic resonance measurements to a forward model for responses of the flowing fluid to derive a parameter selected from a flow speed, longitudinal relaxation times of the flowing fluid, and a combination thereof.

[c9] The method of claim 8, wherein the longitudinal-relaxation-investigation pulse comprises one selected from a inversion-recovery pulse sequence and a saturation-recovery pulse sequence.

[c10] The method of claim 8, wherein the acquisition pulse sequence comprises one selected from a spin-echo pulse sequence and a single pulse.

[c11] The method of claim 8, wherein the fitting is performed

by inversion of the forward model.

[c12] The method of claim 8, further comprising estimating a viscosity of the flowing fluid based on the derived flow speed and a pressure drop across a selected length of a pipe in which the flowing fluid travels.

[c13] The method of claim 12, wherein the estimating is according to one selected from

$$\eta = \frac{\Delta P \cdot r_o^2}{8 \cdot v \cdot L} \quad \text{and} \quad \eta = K \frac{\Delta P}{v},$$

where η is the viscosity, v is an average speed of the flowing fluid, L is the selected length of the pipe, ΔP is the pressure drop over the selected length of the pipe, and r_o is a radius of the pipe, and K is an experimentally determined constant.

[c14] The method of claim 8, further comprising estimating a viscosity of the flowing fluid based on the derived longitudinal relaxation times and a gas-oil ratio of the flowing fluid.

[c15] The method of claim 14, wherein the estimating is according to:

$$\eta_o = \frac{kT}{T_{1,LM} \cdot f(GOR)}$$

where η_o is the viscosity, k is an empirically determined constant for the flowing fluid, T is a temperature in Kelvin, $T_{1,LM}$ is a logarithmic mean of the longitudinal relaxation times of the flowing fluid, and f(GOR) is an empirically determined function of the gas-oil ratio.

[c16] A method for monitoring contamination in a flowing fluid being withdrawn into a formation fluid testing tool using nuclear magnetic resonance, comprising:
applying a static magnetic field to the flowing fluid;
acquiring a suite of nuclear magnetic resonance measurements of the flowing fluid using a pulse sequence comprising a spoiling pulse, a wait time, and an acquisition pulse sequence, wherein the suite of nuclear magnetic measurements have different values for the wait time;
fitting the suite of nuclear magnetic resonance measurements to a forward model for responses of the flowing fluid to derive a property of the flowing fluid; and
monitoring a level of contamination in the flowing fluid

based on the derived property of the flowing fluid.

[c17] The method of claim 16, wherein the property of the flowing fluid comprises one selected from a distribution of longitudinal relaxation times, a logarithmic mean of longitudinal relaxation times, and a combination thereof.

[c18] The method of claim 16, wherein the property of the flowing fluid is a viscosity.

[c19] A nuclear magnetic resonance apparatus, comprising:
a flow pipe including a prepolarization section and an investigation section, wherein the prepolarization section is upstream of the investigation section;
a magnet disposed around the flow pipe for creating a static magnetic field covering the prepolarization section and the investigation section;
an antenna disposed around the flow pipe at the investigation section for generating an oscillating magnetic field having a magnetic dipole substantially perpendicular to a magnetic dipole of the static magnetic field, and for receiving a nuclear magnetic resonance signal; and
a circuitry for controlling generation of the oscillating magnetic field and reception of the nuclear magnetic resonance signal by the antenna.

[c20] The apparatus of claim 19, wherein the circuitry includes

a program having instructions for acquiring a suite of nuclear magnetic resonance measurements of a flowing fluid using a pulse sequence comprising a spoiling pulse, a wait time, and an acquisition pulse sequence.

[c21] The apparatus of claim 20, wherein the acquisition pulse sequence comprises one selected from a spin-echo pulse sequence and a single pulse.

[c22] The apparatus of claim 20, wherein the program further comprises instructions for fitting the suite of nuclear magnetic resonance measurements to a forward model for responses of a flowing fluid to derive a parameter selected from a flow speed, longitudinal relaxation times of the flowing fluid, and a combination thereof.

[c23] The apparatus of claim 22, wherein the fitting is performed by inversion of the forward model.

[c24] The apparatus of claim 22, wherein the program further comprising instructions for estimating a viscosity of the flowing fluid based on the derived flow speed or the derived longitudinal relaxation times.